

Wave Forecasting in Muddy Coastal Environments: Model Development Based on Real-Time Observations

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Grant Number: N00014-03-1-0200, N0001403WX20484

<http://wavcis.csi.lsu.edu>

LONG-TERM GOALS

The objective of the proposed work is to study wave evolution in cohesive sedimentary environments, toward the development of an effective, stochastic model for wave dissipation in these environments. The project will focus on prediction of surface wave evolution over relatively large spatial scales (spatial scales of 100 wavelengths), intermediate-depth to shallow water.

OBJECTIVES

The strong dissipative effects cohesive sedimentary environments have on waves are well known, but little understood. The commonly accepted long wave paradigm (only low frequency motion is affected, due to strong interactions with the bottom), is contradicted by observations (Sheremet and Stone, 2003) showing strong dissipation also in the high frequency bands, where the direct wave-bottom interaction is weak. The goal of this project is to investigate short wave dissipation and develop a theoretical formulation for its mechanisms, and use the results to develop a numerical formulation of dissipation terms, amenable to implementation into existing stochastic spectral wave models (e.g. SWAN).

APPROACH

The observational component of the project is based on the two main ocean-observing systems in operation at Louisiana State University: Earth Scan Lab and WAVCIS. These systems are operational and provide comprehensive real-time satellite and in situ measurements. The project will enhance WAVCIS' capabilities with sediment monitoring sensors.

The simulation component will consist of a fully detailed pilot model, integrated in a quasi-operational,

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 2003		2. REPORT TYPE		3. DATES COVERED 00-00-2003 to 00-00-2003	
4. TITLE AND SUBTITLE Wave Forecasting in Muddy Coastal Environments:Model Development Based on Real-Time Observations				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Louisiana State University,Coastal Studies Institute,,331 Howe-Russell Geoscience Complex,,Baton Rouge,,LA,70803				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 8	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

nowcast mode, with the observation systems. The pilot model will implement theoretical approaches derived from the study, and will serve as a benchmark for skill assessing subsequent parametrizations of wave dissipation developed as MODULES for operational use.

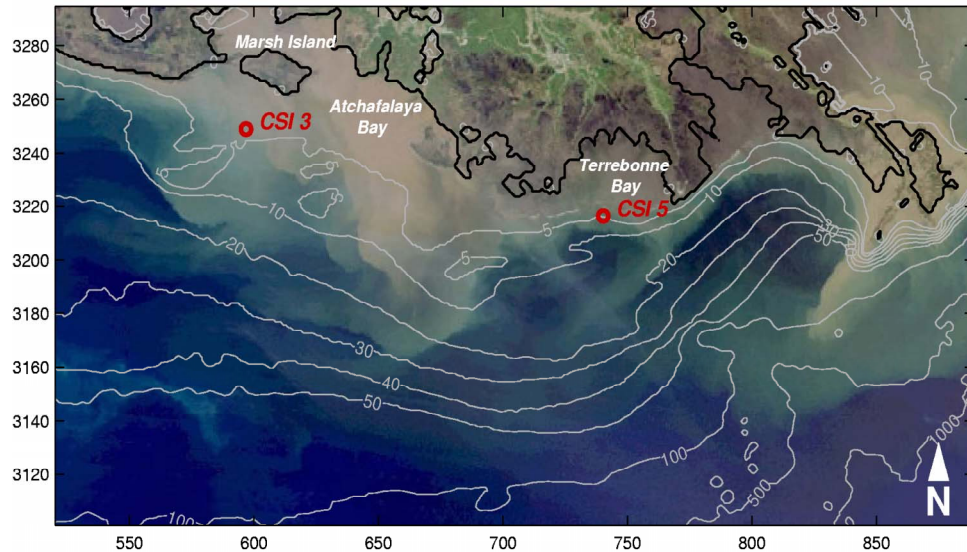


Figure 1. A true-color, Terra-1 MODIS image of the Louisiana coast with the location of WAVECIS stations CSI 3 and CSI 5. Both stations are near the 5-m isobath. CSI 3 is in a muddy environment (brown water), CSI 5 in a sand-dominated environment.

The resulting simulation/observational system (workbench) will help identify the dominant energy exchange mechanisms, their time/spatial scales, ways to uncouple surface wave and fluid-mud/seabed motions. It will also maximize the exposure of development ideas to field data. The database of test cases will be established during the project.

Sheremet and Kaihatu carry out the theoretical and numerical work. Stone oversees the operation of WAVECIS and tasks pertaining to it. Sheremet is responsible for data analysis.

WORK COMPLETED

The main effort has been directed in the first year toward the identification of dominant dissipation mechanisms, especially those active in the higher frequency bands of the wave spectrum, which are not understood. Our observations (Sheremet and Stone, 2003) suggest that sediment re-working might play a role, but lacked sediment concentration data necessary to make a convincing case. A substantial effort has been dedicated during the first year of the project to deploying additional instrumentation for monitoring sediment content in the water column, and integrating it into WAVECIS data stream. Three turbidity meters (OBS - optical backscatter sensors, temperature and salinity sensors) have been deployed at WAVECIS station CSI 3 (muddy bottom) at the provisional locations of 1.5, 2.5 and 3.5 meters above the seabed. Another two are in the process of being deployed at CSI 5 (primarily sandy bottom). CSI 3 is located on the 5 m isobath on the muddy inner shelf off western Louisiana and CSI 5 is located at approximately the same depth but on a sandier bottom 150 km to the east (Figure 1). The sensors are operational, and data are reported every hour.

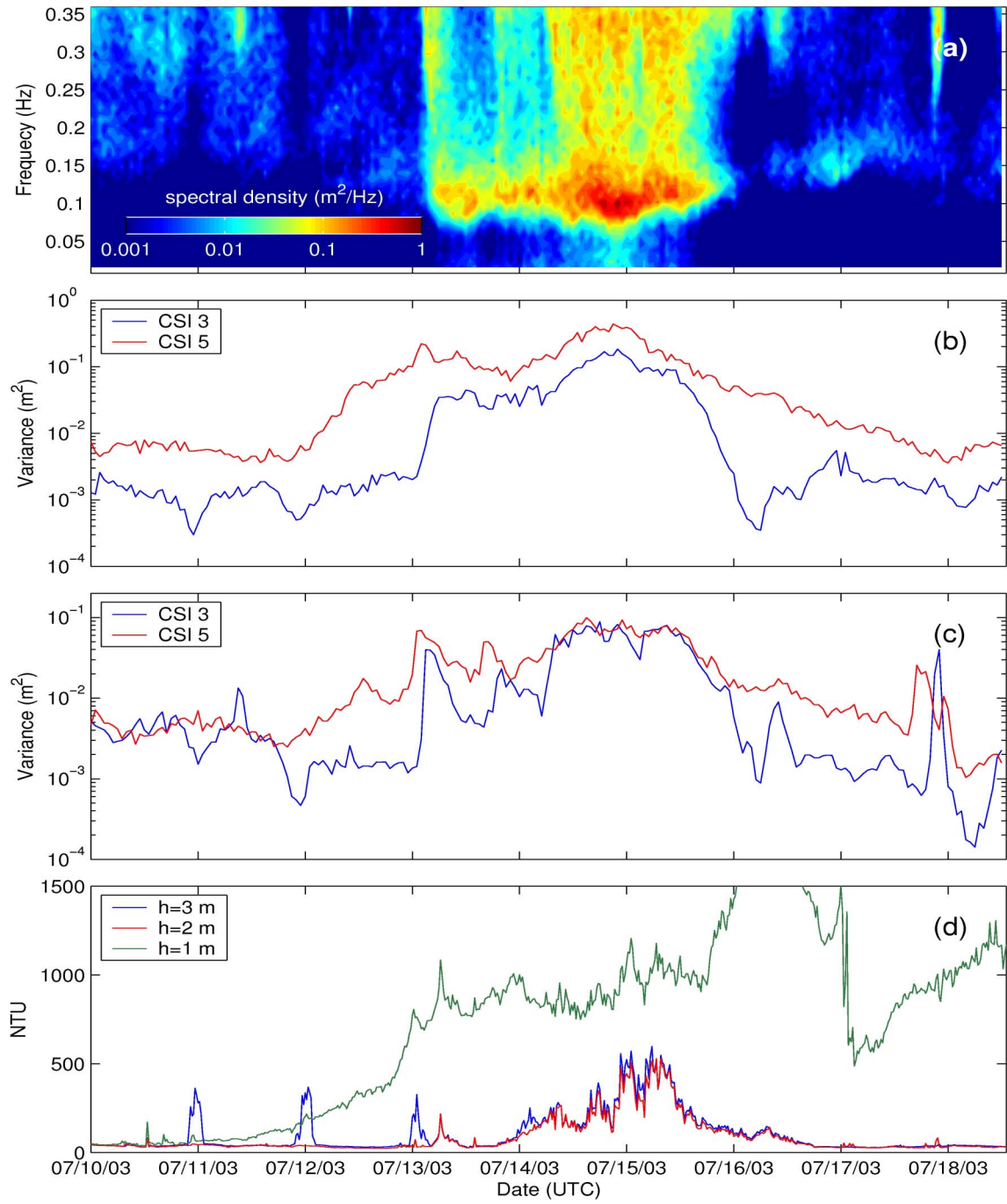


Figure 2. a) Spectral evolution during Claudette (log scale) at CSI 3. Swell ($f < 0.2$ Hz, f frequency) variance at CSI 3 (blue), and CSI 5 (red). b) Seas ($f > 0.2$ Hz) variance. c,d) Turbidity measurements for three OBS located at CSI 3, at 1.5, 2.5 and 3.5 meters from the bottom (green, red, and blue, respectively).

RESULTS

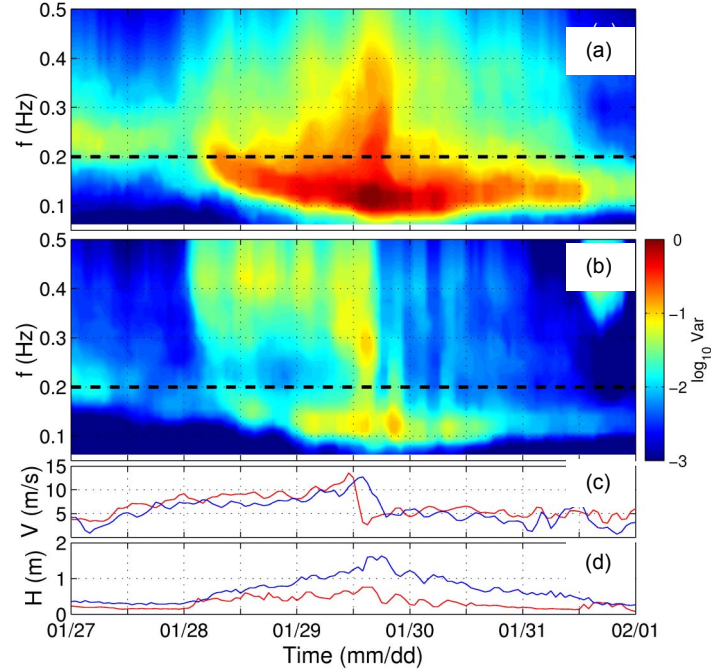


Figure 2 is an example of data from the turbidity meters, acquired during Hurricane Claudette. The storm made landfall along the Texas coast on July 15, 2003. The evolution of water turbidity is plotted in Figure 2d. The spikes recorded by the topmost OBS before the storm are correlated with diurnal low tides, suggesting that they might be related to surface sediment and fresh water influx from the nearby mouth of the Atchafalaya River (the process was not recorded by middle and bottom sensors). As storm waves arrive at the site, turbidity levels show a general increase, associated with sediment resuspension on the bottom. A substantial increase of bottom turbidity two days before the arrival of the storm, is probably due to sediment re-suspension and transport from areas SE of CSI 3.

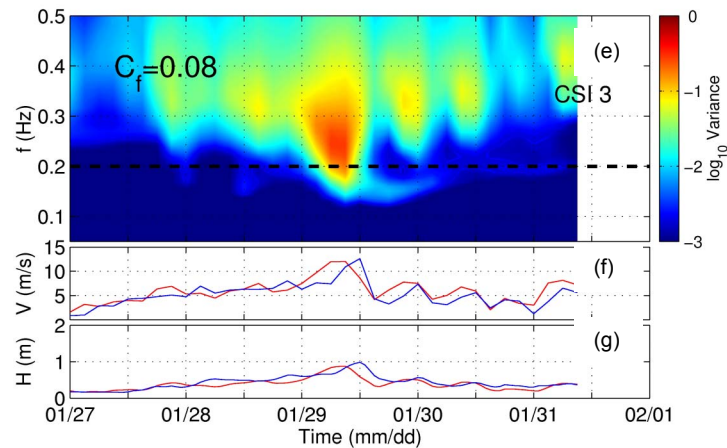


Figure 3. Evolution of wave spectrum during the storm of 27 Jan. - 01 Feb. 2001. a, b) Measured spectra at station CSI 5 and 3, respectively; c) wind speed; d) significant wave height (red - CSI 3, blue - CSI 5, Sheremet and Stone, 2003). e) Simulated spectrum at CSI 3, using SWAN with increased friction coefficient; f) wind speed; d) significant wave height. Dotted line at $f=0.2$ Hz, in a, b and e) separates swell and sea frequency bands.

Sediment resuspension levels at 1.5 m above the bottom are well correlated with swell; the higher layers show an increase of turbidity only at the peak of the storm (compare with Figure 1a), when the signal from the two upper layers are almost identical. The most remarkable element in these plots, however, is the processes taking place in the wake of the storm. The turbidity in the upper layers drops back to normal levels, approximately at the same rate as the decrease in swell energy. In contrast, turbidity in the bottom layer increases in a spectacular fashion, beyond the saturation levels of the bottom sensor (over 1500 NTU, for an approximate 36-hour period). This suggests the formation of a fluid mud layer by settling of suspended sediment, an effect that has been observed before (Allison et al. 2000, with concentrations up to 25 g/l), but at a much coarser time resolution. The formation of the high-turbidity bottom layer is associated with a marked decrease in both swell and sea energy at CSI 3

(Figures 2b and 2c). These observations support the assumption that short wave attenuation mechanisms are strongly connected to sediment re-working.

The turbidity sensors are still in a testing stage, with data continuously monitored to investigate an optimal location for the sensors (e.g. Figure 2 suggests that 0.5, 1 and 2 m heights above the sea bed might be a better choice). Procedures are under development to calibrate the sensors and, using water samples, derived from turbidity density and concentration information. Complete datasets of current, wave, sediment and atmospheric conditions are archived continuously.

A number of numerical experiments have been conducted using SWAN, to assess the degree to which dissipation mechanisms already implemented in the model could represent observed wave attenuation processes. The exercise consisted essentially of artificially increasing the value of the bottom friction coefficient. The JONSWAP dissipation formulation used in SWAN (Hasselmann et al. 1973, Collins 1972, Bows and Komen 1983, Madsen et. al 1988), is similar to Putnam and Johnson (1949), cited in Lee (1995). An example of numerical results for spectral evolution at station CSI 3 are given in Figure 3e, side by side with observations (Figure 3b), for a friction coefficient value of 0.08 (SWAN default value is 0.067). The same value of bottom friction is assumed for the entire computational domain. Increasing the friction coefficient has the effect expected from a long-wave -based formulation: long waves are strongly dissipated, while the short wave band shows very little change. Increasing the values further completely wipes out the low frequencies with a slowly increasing effect on short waves. The highest frequencies remain essentially unaffected. A friction-based wave dissipation module does not account for the full physics of mud-induced wave attenuation.

Guided by preliminary results from observations and numerical tests, preliminary work has started in the development of a spectral formulation for surface wave propagation over a two-layered fluid (a water layer with low mud concentration, on top of a thin fluid-mud layer). The fluid mud layer is assumed Newtonian (concentrations of up to 1 g/l). The model is a generalization of the linear model of Dalrymple and Liu (1978), with extensions by Ng (2000), and uses the formulations of Kaihatu and Kirby (1995) and Agnon and Sheremet (2000) (mild slope equation formalism). The dispersive models are chosen primarily because the high frequencies of interest are far beyond the capabilities of formulations based on standard Boussinesq models (Freilich and Guza 1984) and quite possibly even extended Boussinesq models (Madsen and Sørensen 1993). At present, the model assumes a mud state apriori (e.g. vertical distribution of mud, thickness of mud layer).

IMPACT/APPLICATIONS

Much of the present and near-future Navy capability in predicting regional and nearshore processes

assumes a sandy, non-cohesive sedimentary environment. The present research enhances this capability by identifying processes and developing mechanisms, which would allow expansion of Navy modeling activities into areas of non-sandy and/or cohesive bottom sediment composition.

RELATED PROJECTS

In FY04, the Marine Geosciences Division of the Naval Research Laboratory will begin work on a large, multi-year Research Option project entitled “Coastal Dynamics of Heterogeneous Sedimentary Environments” (PI: Dr. K. Todd Holland). We intend to collaborate closely with NRL scientists in this work. Details of the project can be found at:

<http://www7440.nrlssc.navy.mil/littoral%20dynamics/CDHeteroEnviro.html>

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